§19. Effect of Flow Shear on Current-Diffusive Ballooning Mode

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Physics of H-mode has recently attracted attentions. A theory based on the bifurcation of the radial electric field, E_r, was proposed [1] and has been supported by experiments. It has also been suggested that the steep radial gradient of E_r can improve the stability and reduce the fluctuation level. Recently, a new theory of the turbulence and anomalous transport in the toroidal plasmas was developed. The nonlinear current-diffusive ballooning instability was solved and the theoretical model of the L-mode transport was obtained [2]. The understanding of the H-mode transport requires the formalism of the nonlinear current diffusive ballooning mode in the presence of the flow shear.

We study a circular tokamak with the toroidal coordinates (r, θ, ζ). The reduced set of equations is used: the equation of motion, $n_i m_i \{d(\nabla_\perp^2\phi)/dt - \mu\nabla_\perp^4\phi\} = B^2\nabla_{/\!/}J + B\nabla p\times\nabla(2r\cos\theta/R)\cdot\zeta$, generalized Ohm's law, $E + v\times B = J/\sigma - \nabla_\perp^2\lambda J$, and the energy balance equation, $dp/dt = \chi\nabla_\perp^2 p$. The E×B nonlinear interactions are renormalized in a form of the thermal conductivity χ, ion viscosity μ and current-diffusivity λ. Other notation is standard. The doppler shift of frequency is offset for the homogeneous E×B rotation. Only the contribution of E_r' to d/dt is retained.

The ballooning transformation is employed as $\tilde{p}(r, \theta, \zeta) = \Sigma\exp(-im\theta + in\zeta)\int\tilde{p}(\eta)\exp\{im\eta - inq\eta\}d\eta$, (q is the safety factor) [3], since we are interested in microscopic modes. Eliminating $\tilde{\Phi}$ and $\tilde{J}$ from basic equation, we have the eigenmode equation for $\tilde{p}$

$$\frac{d}{d\eta}\frac{F}{\hat{\gamma}+\Xi F+\Lambda F^2}\frac{d}{d\eta}\left[\hat{\gamma}+\omega_{E1}\frac{d}{d\eta}+KF\right]p +$$

$$\alpha[\kappa+\cos\eta+(s\eta-\alpha\sin\eta)\sin\eta]p$$

$$-\left[\hat{\gamma}+\omega_{E1}\frac{d}{d\eta}+MF\right]F\left[\hat{\gamma}+\omega_{E1}\frac{d}{d\eta}+KF\right]p = 0.$$

Length and time are normalized to a and τ_{Ap}, respectively, $(\tau_{Ap} \equiv a\sqrt{\mu_0 m_i n_i}/B_p)$. Notation $\Xi = n^2q^2/\hat{\sigma}$, $\Lambda = \hat{\lambda}n^4q^4$, $K = \hat{\chi}n^2q^2$, $M = \hat{\mu}n^2q^2$, γ is the growth rate, $s = r(dq/dr)/q$, $F = 1 + (s\eta - \alpha\sin\eta)^2$, $\kappa = -(r/R)(1 - 1/q^2)$ (average well), $\alpha = q^2\beta'/\varepsilon$, and other notation is standard. The parameter ω_{E1} denotes the effect of the shear of E_r,

$$\omega_{E1} = \tau_{Ap}(dE_r/d\hat{r})(srB)^{-1}.$$

If we neglect ω_{E1}, the eigenvalue equation reduces to the transport-driven ballooning mode equation for the L-mode plasma [2]. The ideal MHD mode equation [3] is recovered by further taking $1/\hat{\sigma} = \hat{\lambda} = \hat{\chi} = \hat{\mu} = 0$.

These equations provide the basis for solving the transport coefficient in the H-mode plasmas.

References

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